Evaluation of the Stormwater Management StormFilter® cartridge for the removal of SIL-CO-SIL 106, a synthetically graded sand material:

Coarse perlite StormFilter cartridge at 28 L/min (7.5 gpm)

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Overview

This experiment assesses the ability of a Stormwater Management StormFilter® (StormFilter) cartridge containing coarse perlite to remove total suspended solids and decrease turbidity from simulated stormwater. Under controlled conditions, 12 runoff simulations (sims) were performed using influent TSS with a silt texture (20% sand, 80% silt, 0% clay), variable event mean concentrations (EMCs) between 25 and 300 mg/L, and a filtration rate of 28 L/min (7.5 gpm) (100% design, per cartridge, operating rate for this configuration). The mean TSS (silt) removal efficiency for the coarse perlite StormFilter cartridge configuration was determined using regression statistics and found to be 77% (P=0.05: L_1=76%, L_2=78%) over the range of influent EMCs tested. An additional sim was conducted to determine the effect of a larger storm size by sending a larger volume of water through the cartridge than the other 12 sims. No difference in TSS removal performance was observed for the larger volume simulated using a target EMC of 300 mg/L. Turbidity data was also collected and indicated that the coarse perlite StormFilter cartridge was capable of a 40% (P=0.05: L_1=22%, L_2=57%) mean decrease in turbidity.

Introduction

The goal of testing the coarse perlite StormFilter cartridge was to determine its TSS removal performance given a manufactured silt as the contaminant source. Utilizing a standardized particle size distribution eliminates the contaminant as a variable, thereby providing opportunities to compare the StormFilter silt removal efficiencies with other systems utiltizing the same contaminant source, in addition to cross comparing other variables of StormFilter use.

The methodology applied to this test is comparable to the methodology used in previous cartridge-scale StormFilter testing to evaluate TSS removal efficiencies (Calvert and de Ridder, 2002; de Ridder et al. 2002a; de Ridder et al., 2002b). An examination of particle size distribution was applied to the silica soil sample. An evaluation of turbidity reduction was also performed using the silt textured silica.

Procedure

Media

Coarse perlite media filled the 178 mm (7 in) media compartment radius of the cartridge for this experiment. Perlite is a naturally-occurring volcanic mineral product and is a common raw material obtainable from a variety of suppliers. Lightweight, chemically inert, coarse, and granular, it is an effective physical filtration media.

Prior to testing, the coarse perlite StormFilter cartridge used for testing was flushed so as to remove the residual dust within the media left over from the cartridge production process, as well as to allow the media to approach a typical, wet operating condition. Individual, ~800-L, tap water flushes were performed according to the operation segment of the procedure section. Flushing was ceased after four flushes, at which point the effluent TSS EMC had decreased to ND (<2 mg/L) from an initial value of 6 mg/L.

Contaminant

For the purpose of this experiment, TSS is defined according to EPA method 160.2 with the additional constraint of a maximum particle size of 1000 µm. This definition of TSS is in accordance with APWA (1999) and Portland BES (2001) protocols for the laboratory testing of stormwater treatment technologies.

A commercial ground silica product, SIL-CO-SIL 106 (SCS 106), was used for silt TSS simulation. This product is manufactured by the US Silica Company and the sample used for testing originated from the Ottowa, IL plant.

Two particle size analyses were performed internally on SCS 106 using hydrometer and sieve techniques (Gee and Bauder, 1986). The resulting average particle size distribution, shown in Figure 1, revealed a silt texture consisting of 20% sand, 80% silt, and 0% clay-sized particles.

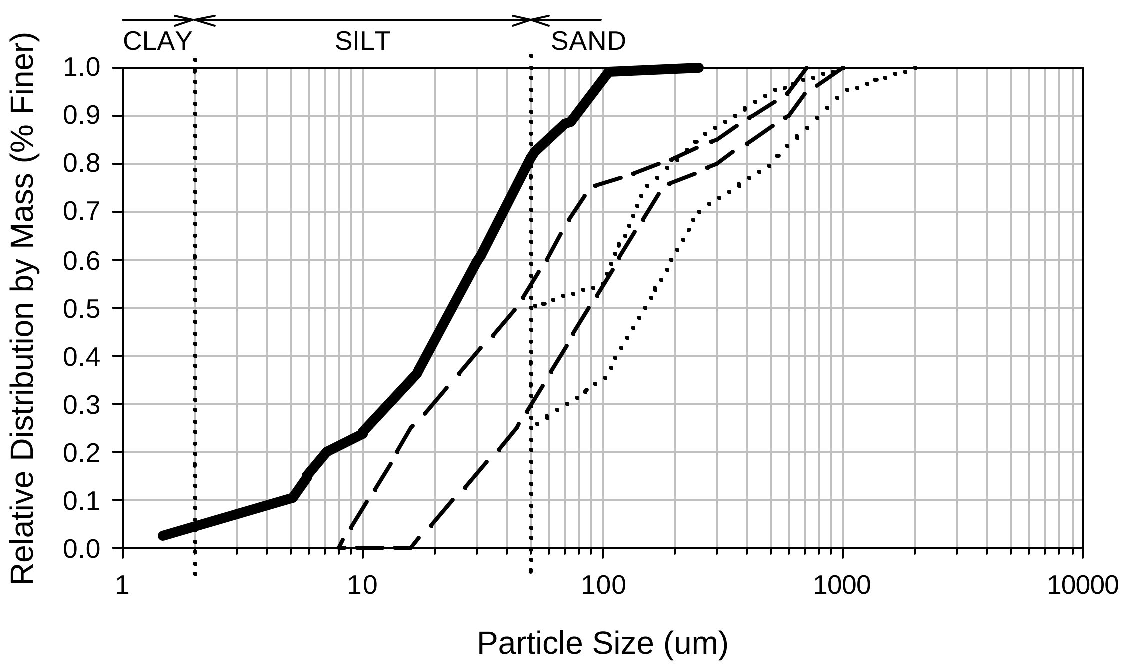

Figure 1. Particle size distribution for SIL-CO-SIL 106. Sand/silt/clay fractions according to USDA definitions are approximately 20%, 80%, and 0% for SIL-CO-SIL 106, indicating that the texture corresponds to a silt material. Dashed and dotted lines indicate particle size distribution ranges recommended by Portland BES (2001) and APWA (1999), respectively, for materials used for laboratory evaluation of TSS removal for stormwater BMP's.

The SCS 106 was given the opportunity to hydrate prior to experimentation so as to promote the disintegration of any aggregate particles that may have been present. Based upon an 400-L influent volume, target TSS EMCs were determined for each planned contaminated simulation and associated masses of contaminant were placed in 1-L HDPE bottles of tap water--one bottle of concentrate per planned contaminated simulation. Target TSS EMCs consisted of 25 mg/L increments ranging from 25 to 300 mg/L. The order in which they were used was randomly selected using random number techniques so as not to bias the performance results. The concentrates were then left out at room temperature for a day and periodically shaken to encourage the dissolution of any aggregates. Following this initial equilibration period, the concentrates were refrigerated until needed.

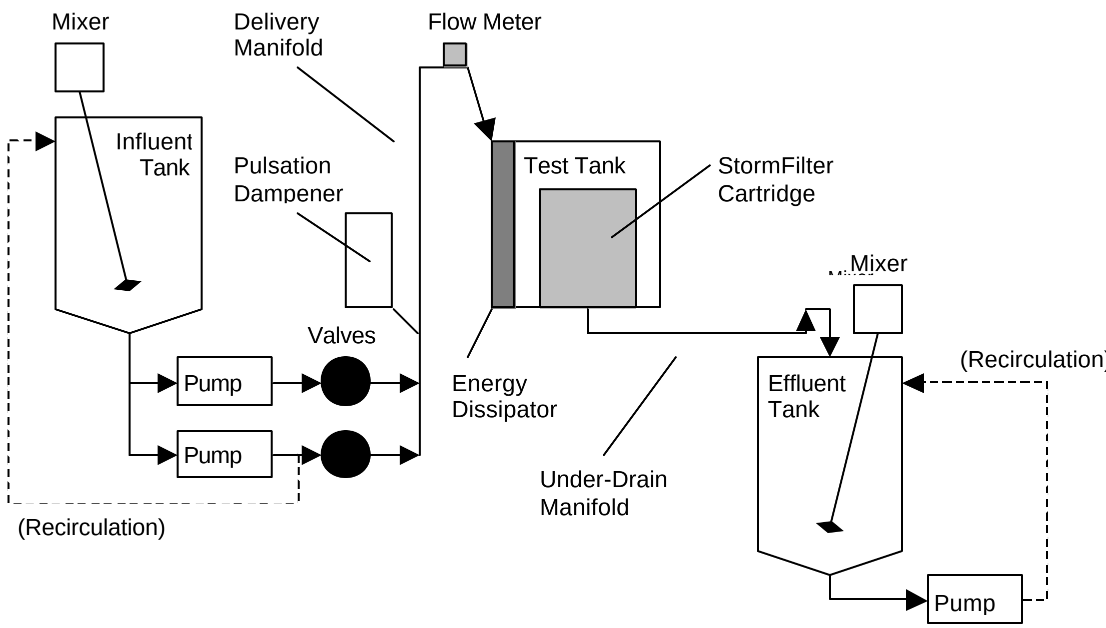

Figure 2. Schematic diagram of the cartridge-scale test apparatus. Arrows indicate flow pathways. Dashed arrows indicate recirculation pathways employed during influent and effluent sampling.

Test Apparatus

The typical precast StormFilter system is composed of three bays: the inlet bay, the filtration bay, and the outlet bay. Stormwater first enters the inlet bay of the StormFilter vault through the inlet pipe. Stormwater in the inlet bay is then directed through the flow spreader, which traps some floatables, oils, and surface scum, and over the energy dissipator into the filtration bay where treatment takes place. Once in the filtration bay, the stormwater begins to pond and percolate horizontally through the media contained in the StormFilter cartridges. After passing through the media, the treated water in each cartridge collects in the cartridge's center tube from where it is directed into the outlet bay by an under-drain manifold. The treated water in the outlet bay is then discharged through the single outlet pipe to a collection pipe or to an open channel drainage way.

The test apparatus used for this experiment simulates the filtration bay component of a full-scale StormFilter system, including the energy dissipator. Since the design of full-scale StormFilter systems varies, and since the operation of a full-scale system in the laboratory environment would require very large volumes of water, the use of the most common components among all of the possible designs, the StormFilter cartridge and the associated volume of filtration bay area, were selected so as to provide a very conservative estimate of StormFilter performance.

Unlike chemical removal testing, suspended solids removal testing is challenging due to the relatively large, dense, insoluble nature of the contaminant. Care must be taken to maintain the suspension of solids within the influent and effluent reservoirs, maintain the suspension of solids within the conveyance system, avoid the fouling of flow metering devices, avoid the destruction of individual solids by the pumping system, and avoid the destruction of the pumping system by the solids.

The apparatus used for this experiment was carefully designed to meet these challenges. Figure 2 demonstrates the layout of the test apparatus. Influent and effluent storage was provided by individual 950-L (250 gallon), conical bottom, polyethylene (PE) tanks (Chem-Tainer). The conical bottom design ensured full drainage of the tanks, in addition to the movement of all solids out of the tanks. Four, evenly-spaced, vertically-oriented baffles, measuring 91-cm x 8-cm x 1-cm (36-in x 3-in x 1/2-in) (LxWxThickness), affixed to the sidewalls of the influent and effluent tanks prevented mixer-induced vortexing. Suspension of solids within the tanks was maintained by individual, 1/2-hp, electric, propeller mixers (J.L Wingert, B-3-TE-PRP/316). The propeller design maximized the vertical circulation of solids within the tank and ensured the homogeneity of the mixture. Peristaltic-type pumps (Vanton, 19 L/min (5 gpm) Flex-i-liner) were used to re-circulate water through the underlying manifolds of both tanks during sampling so as to eliminate any possibility of sediment accumulation in the manifolds.

Influent was carried from the influent tank by two peristaltic-type pumps (Vanton, 38 L/min (10 gpm) and 19 L/min Flex-i-liner) plumbed into a common PVC intake manifold below the influent tank and discharged into a common delivery manifold of 25-mm (1-in) PVC pipe. The peristaltic pumps specified for use in this experiment were selected because of their ability to handle solids to 1-mm without breaking down the solids themselves. Also, despite the associated head loss, 25-mm diameter pipe was selected to ensure high flow velocities to maintain the suspension of solids during transfer. The pulsating flow generated by the pumps also helped to eliminate settling within the piping.

Discharge from the delivery manifold into the 56-cm x 56-cm x 62-cm (22-in x 22-in x 24.5-in) (LxWxH) polypropylene StormFilter cartridge test tank was by free discharge into the tank-mounted energy dissipator, which consisted of a vertical length of 76-mm (3-in) PVC pipe with an open bottom and multiple 3-mm (1/8-in) wide horizontal slots along its entire length. The energy dissipator was used to minimize the re-suspension of settled material within the test tank by restricting turbulence to the region within the dissipator. Discharge from the StormFilter cartridge test tank into the effluent tank was through direct discharge from the under-drain manifold component of the test tank over the top of the effluent tank.

Flow into the StormFilter cartridge test tank was controlled by individual ball valves placed between each pump and the delivery manifold, and flow was monitored with a paddle-wheel type electronic flow meter (GF Signet, Rotor-X Low Flow) coupled with a flow transmitter with totalizer (GF Signet, Processpro). A pulsation dampener, consisting of a constant air pocket constructed out of a capped length of 76-mm PVC pipe, was fitted to the delivery manifold to dampen the pulsating flow generated by the peristaltic-type pumps.

Operation

The operational procedure consisted of performing multiple runoff simulations (sims) using the same StormFilter cartridge test tank and apparatus described in the Test Apparatus section above. Sims proceeded as follows.

The influent tank was filled with ~400-L of tap water, and the predetermined contaminant concentrate was added to the influent tank. The influent tank was then mixed thoroughly with the mechanical mixer while influent was re-circulated through the lowest port in the underlying manifold and allowed to equilibrate for 5 to 10 minutes before sampling.

Following influent sample collection, re-circulation was stopped and the influent was pumped into the test tank energy dissipator via the delivery manifold. Flow rate was controlled through periodic adjustment of the influent flow valves so as to maintain a constant flow rate reading of 28 L/min ± 1.9 L/min (7.5 gpm ± 0.5 gpm). Mixing and re-circulation of the effluent reservoir was started towards the end of a sim to allow effluent equilibration prior to sample collection.

The influent pumps were operated until as much of the influent had been pumped from the influent reservoir and underlying manifold as was possible, at which point the influent pumps were shut down and the StormFilter cartridge test tank was allowed to drain. Once the float valve within the StormFilter cartridge closed, effluent was sampled and the total sim volume reported by the totalizer was recorded.

Sampling

Composite samples of influent and effluent were collected for TSS and turbidity analysis. Two sets of samples were collected for internal TSS and turbidity analysis and an additional set was collected for TSS analysis by Severn Trent Laboratories (STL), Tacoma, WA. Results produced by STL were used for TSS removal performance evaluation while internal results were used for TSS removal performance data quality assurance and turbidity removal performance evaluation. For this document, a set is defined as a collection of influent and effluent sample pairs corresponding to a specific sim. To increase the overall accuracy of the experiment and to assess the variation of results acquired by STL, duplicate samples for 3 of the 12 sims were included in the samples sent to STL.

Sample handling was performed in accordance with standard handling techniques. All samples to be tested for TSS were promptly refrigerated following collection. Samples were shipped to the laboratory in coolers, accompanied by ice-packs and chain-of-custody documentation for analysis within seven days. STL performed TSS analysis according to the "whole-sample" variation of EPA method 160.2 after the findings of de Ridder et al. (2002b).

Samples were extracted with a 1-L PE, 1.2-m ladle using a sweeping motion across and through the center of the reservoir. Eight 1-L grab samples were collected in an 8-L churn sample splitter (Bel-Art Products) for composite sample extraction according to the manufacturer's directions. Care was taken to transfer all solids from the ladle through quick emptying of the ladle while using a swirling motion. The churn splitter was used to dispense approximately 600 mL of composite sample into 1-L HDPE, wide-mouthed bottles. The sampling ladle and churn splitter were subject to a high-pressure wash between uses.

Internal Analysis

The analytical method described by ASTM D 3977, Method B, was used for internal TSS analysis. The only deviations from the procedure involved: 1) the use of 76-mm plastic buchner funnels instead of porcelain or borosilicate glass crucibles; 2) the use of aluminum weighing dishes for filter drying; 3) the use of 76-mm ProWeigh (Environmental Express) glass fiber filters instead of Whatman type 934-AH. The ASTM D 3977, Method B, method is more accurate for stormwater TSS analysis than EPA method 160.2 since it calls for the use of the whole sample volume (de Ridder et al, 2002b). The "whole-sample" variation of EPA method 160.2 was performed by STL since ASTM analytical methods are not widely used by commercial analytical laboratories, and since the "whole-sample" variation makes this method substantially the same as the ASTM method due to the use of the entire sample volume.

Turbidity, a measure of the light-dispersing characteristics of a fluid, was measured using a bench-top turbidimeter (LaMotte 2020). The sample was shaken in its bottle immediately before transfer, via a pipette, to the turbidimeter tube. The tube was wiped clean of moisture using lint-free wipes and then shaken, taking care to maintain a clean tube surface, prior to insertion into the turbidimeter. The pipette and turbidimeter tube were rinsed with deionized water between each use.

Results

TSS removal and turbidity results are shown in Table 1. The distribution of applied influent concentrations resulted in a good range of data. The discrete efficiencies, efficiencies of individual pairs of associated influent and effluent TSS EMCs, reveal a wide variety of results that generally increase with increasing influent TSS EMC. There is no evident trend for the system's effect on turbidity.

Table 1. Summary of influent and effluent TSS EMCs and turbidity along with TSS removal and turbidity decrease results shown according to decreasing influent TSS EMC. Bracketed values indicate internally derived results and associated calculations. Duplicate samples are denoted by sims with a ".2" suffix. The shaded row displays an increased storm size (sim volume) simulation.

Influent TSS EMC (mg/L)	Effluent TSS EMC (mg/L)	Discrete TSS Removal Efficiency	Average Influent Turbidity (NTU)	Average Effluent Turbidity (NTU)	Discrete Decrease in Turbidity	Sim	Sim Volume (L)
27 [29]	9 [9]	67% [69%]	[3.0]	[2.9]	[3%]	8	391
48 [52]	14 [14]	71% [73%]	[7.5]	[4.7]	[37%]	1	402
69 [76]	19 [18]	72% [76%]	[11]	[7]	[36%]	2	409
94 [101]	25 [25]	73% [75%]	[10]	[8.8]	[12%]	11	397
94	26					11.2	
109 [123]	31 [30]	72% [76%]	[11]	[11]	[0%]	6	395
135 [148]	34 [33]	75% [78%]	[25]	[12]	[52%]	3	402
159 [175]	40 [40]	75% [77%]	[20]	[16]	[20%]	9	397
186 [193]	48 [45]	74% [77%]	[20]	[17]	[15%]	10	400
182	43					10.2	
211 [226]	52 [51]	75% [77%]	[32]	[17]	[47%]	5	387
227 [242]	58 [58]	74% [76%]	[29]	[22]	[24%]	12	403
256 [268]	61 [59]	76% [78%]	[23]	[21]	[9%]	7	397
281 [294]	67 [64]	76% [78%]	[45]	[30]	[33%]	4	388
283	66					4.2	
271 [287]	74 [72]	73% [75%]	[47]	[32]	[32%]	13	792

Discussion

Comparison of internal and external TSS analytical methods

An analysis of covariance between internal and external TSS analyses reveals a difference between the results; that is, statistically, the results do not appear to represent the same population. Influent TSS EMCs measured internally yielded higher concentrations than those measured externally, yet the effluent concentrations are comparable.

A possible source of error may lie in the white color of the SCS 106, which makes it difficult to distinguish from the white shade of the HDPE sample bottle and thus visually assess sample removal from the container. Not having been informed as to the nature of the contaminant, a laboratory analyst may easily overlook SCS 106 particles remaining in sample bottle after dispensing the liquid to a filter. This possible oversight negatively impacts removal efficiency results, and was also observed by de Ridder et al. (2002b).

Variant storm size

It was initially believed that the increased volume would create a dilution effect and reduce the impact on effluent TSS concentration caused by the release of perlite dust and residue from the media. The final storm simulation yielded 73% removal of TSS and a 32% reduction in turbidity for a storm size twice the size of the preceding 12 simulations, an approximately 800 L sim volume compared to the previous 400 L sims. These results compared to those of another simulation of 300 mg/L target influent TSS EMC (Sim 4) show that there is no apparent difference in either TSS or turbidity reduction due to increased storm size.

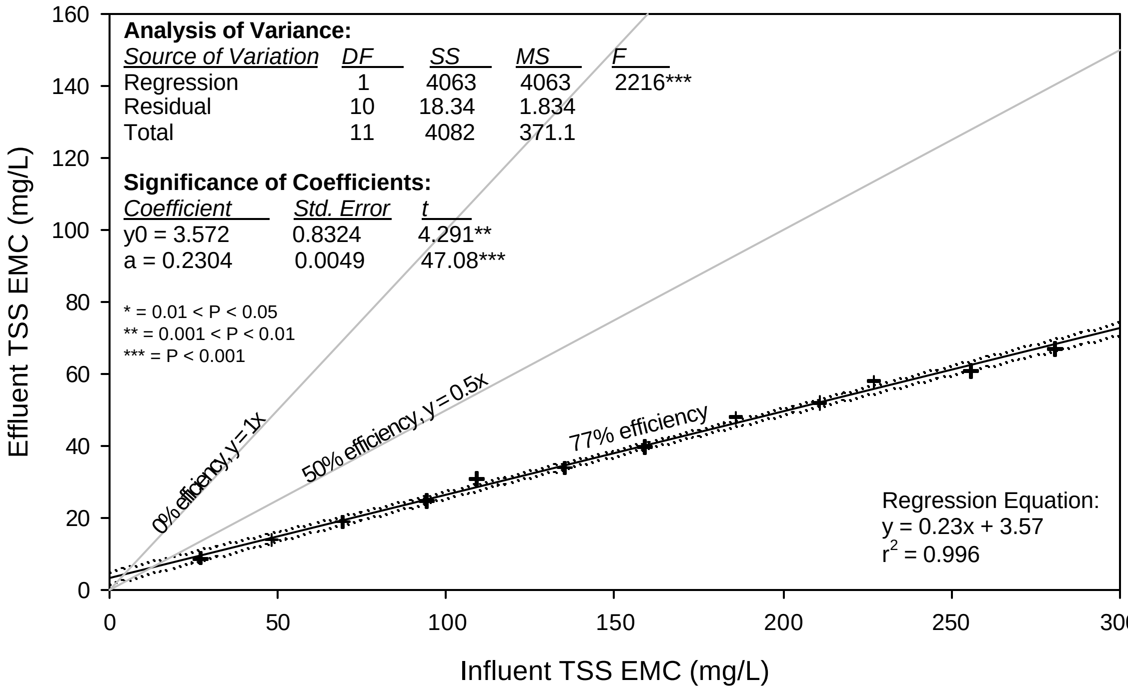

Figure 3. Regression analysis applied to the results of external (STL), influent and effluent TSS data associated with the estimation of the SCS 106 TSS removal efficiency of the coarse perlite StormFilter cartridge. The solid line is the regression. The dotted lines signify the lower and upper 95% confidence intervals. Results of regression significance testing indicates a significant ($P<0.001$) relationship between influent and effluent TSS EMC.

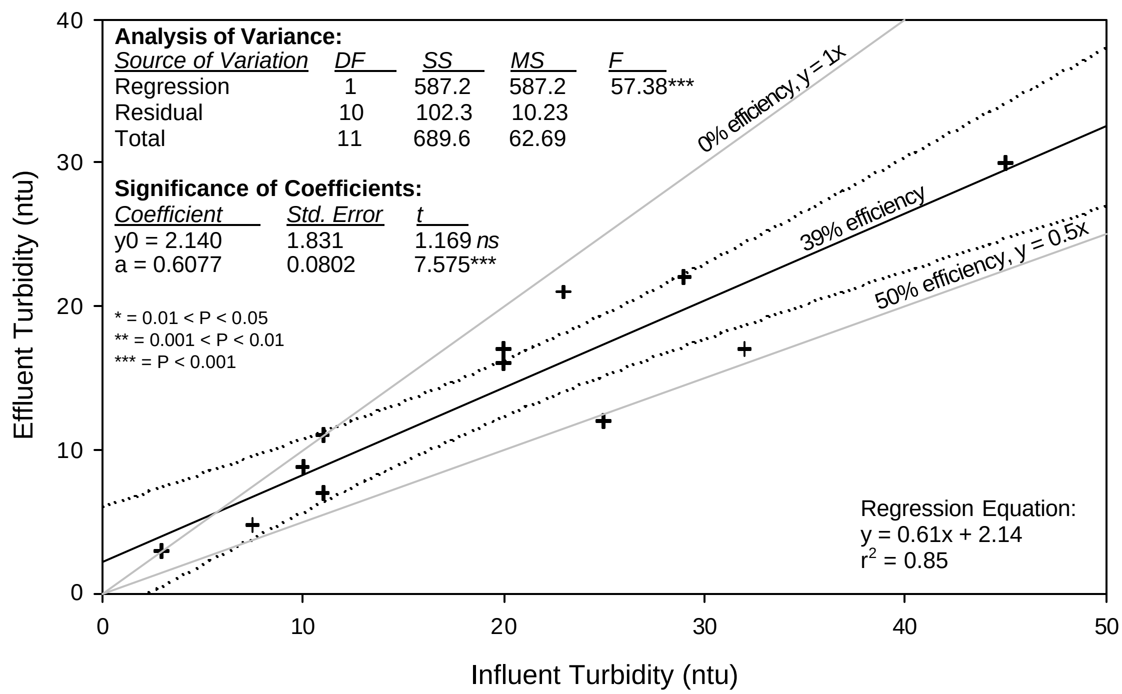

Figure 4. SCS 106 turbidity reduction of the coarse perlite StormFilter cartridge. The solid line is the regression. The dotted lines signify the upper and lower 95% confidence intervals. Results of regression significance testing indicates a significant ($P<0.001$) relationship between influent and effluent turbidity.

System performance evaluation

The graphed results of the external TSS analysis, displayed in Figure 3, show a regressed removal efficiency of 77% (P=0.05: L_1=76%, L_2=78%), which is calculated by subtracting the slope of the regression from 1, then multiplying by 100. A high coefficient of determination (r^2) of 0.996 signifies a tight fit of the data points to the regression equation.

In addition to TSS removal efficiency evaluation, this experiment presented an ideal opportunity to analyze the effect of the coarse perlite StormFilter cartridge configuration operating at 28 L/min on turbidity reduction. The wide range of concentrations of SCS 106 derived TSS used in the test provided a large range of influent turbidity values. The decrease in turbidity associated with the coarse perlite test is less than the reduction of SCS 106 TSS. Figure 4 shows the distribution of turbidity test results.

Because turbidity is dependent on the suspension of fine materials, it can be concluded that the coarse perlite StormFilter cartridge configuration operating at 28 L/min is more effective at removing the coarse sediment associated with TSS than the fine sediment associated with turbidity. The mean turbidity reduction was observed to be 39% (P=0.05: L_1=21%, L_2=57%).

Conclusions

The tests utilizing SCS 106 as a contaminant generated results for the assessment of the silt TSS and turbidity removal efficiency of the coarse perlite StormFilter cartridge. The use of standardized sediment allows the results from laboratory evaluations of the TSS removal performance of stormwater treatment systems to be easily compared. In summary:

1. A coarse perlite StormFilter cartridge test unit, operating at 28 L/min, and subject to TSS with a silt texture (20% sand, 80% silt, and 0% clay by mass) originating from SCS 106 provides a mean TSS removal efficiency of 77% (P=0.05: L_1=76%, L_2=78%);
2. A coarse perlite StormFilter cartridge test unit, operating at 28 L/min, and subject to TSS with a silt texture (20% sand, 80% silt, and 0% clay by mass) originating from SCS 106 provides a mean turbidity reduction of 39% (P=0.05: L_1=22%, L_2=57%);
3. Doubling the sim volume from 400-L to 800-L does not have a noticeable impact on discrete TSS removal efficiency;
4. The difference between internal and external laboratory analyses of TSS for the influent samples may be due to the loss of coarse particles during sample transfer to the filter because of the similarity in color between the particles and the sample bottle.

References

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